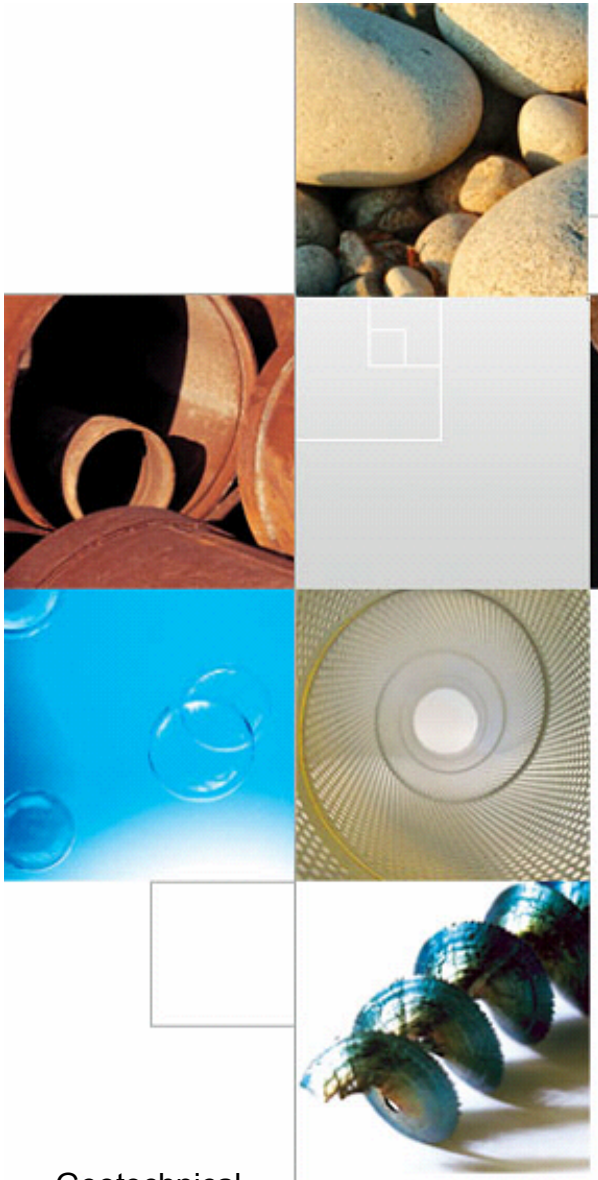

Presented By:

Francis D. Leathers, P.E. and
Michael P. Walker, P.E.

August 3, 2005

M^3 – Modeling, Monitoring and Managing

A Comprehensive Approach to Controlling Ground Movements for Protection of Existing Structures and Facilities

Geotechnical, Environmental and Water Resources Engineering

GEI Consultants

M^3 – Modeling, Monitoring and Managing

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- Comprehensive approach to controlling ground movements during deep excavations
- Actively manage soil and structure performance to protect existing structures and facilities
  - Safety
  - Structural integrity
  - Operations
- Based on fundamental understanding of
  - Soil behavior
  - Structure behavior
  - Soil – Structure interaction

M^3 – Modeling, Monitoring and Managing

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- Enhancement of the "Observational Method"
  - Pro-active approach to managing soil and structure behavior
  - Replaces "wait and see what happens, then adjust approach"
  - Invest in engineering and ability to control behavior
  - Better framework to utilize past experience in design
  - Better framework to evaluate and learn from current experience
- Benefits
  - Perform projects conventionally thought to be "too risky"
  - Improved risk management and confidence
  - Reduced chance of schedule delay
  - Potentially lower total cost

Case Studies

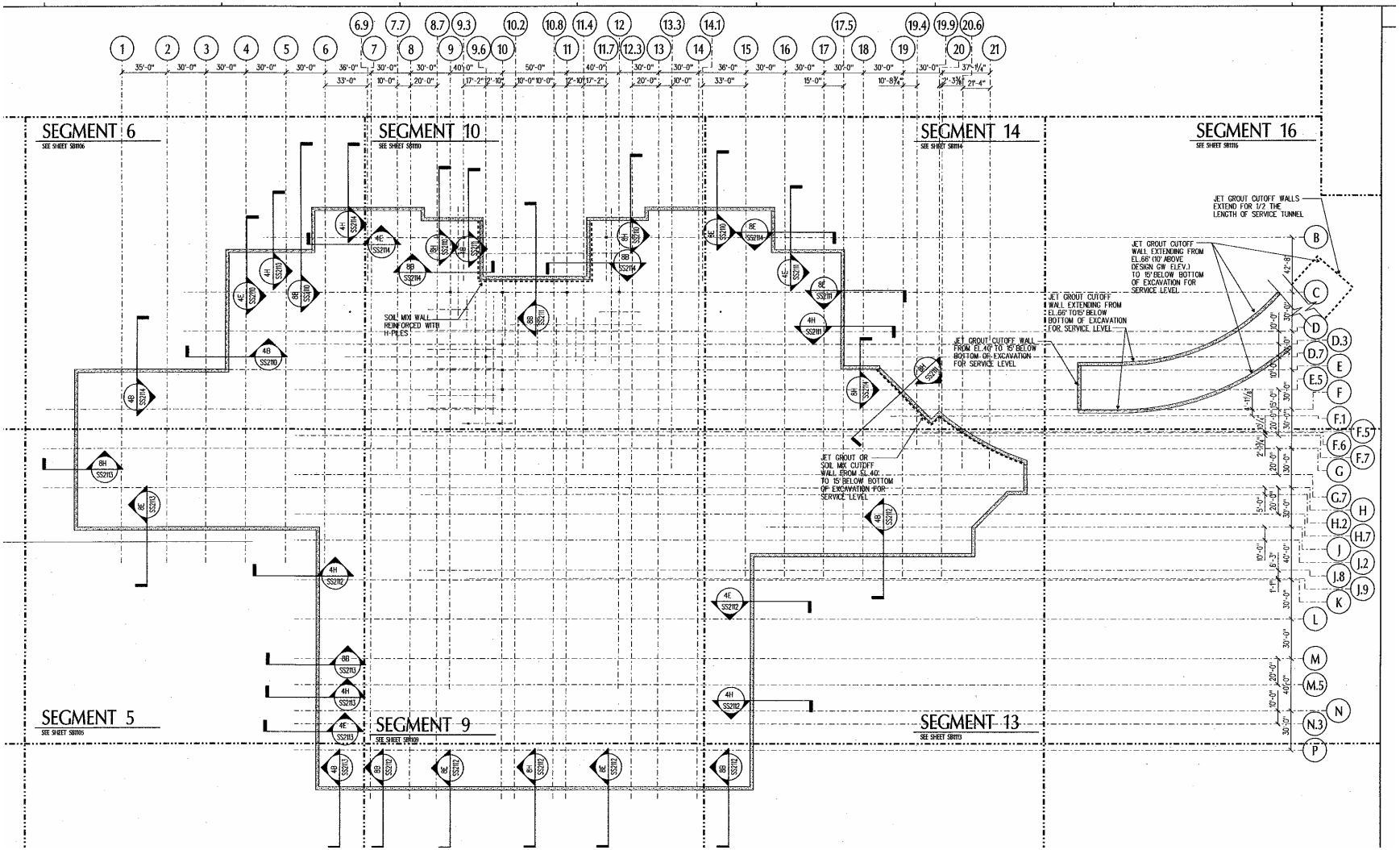
- U.S. Capitol Visitors Center
  - GEI was engineer for excavation support subcontractor, Nicholson Construction
  - Very strict movement criteria to protect very heavy, sensitive historic structure
  - Controlled ground movement to 0.4-inch settlement adjacent to 60-foot deep excavation

- Tunnel Jacking Pit Headwalls for Boston's Central Artery/Tunnel Project
  - GEI was engineer for general contractor, Slattery, Interbetton, White and Perini JV
  - Provided analysis and design of jacking pits
  - Pits subjected to very large and unusual loads from ground freezing and jacking
  - Designed headwalls to accommodate 8- to 15-inches of lateral movement due to ground freezing

Project Goal -
U.S. Capitol Visitors Center

The Site

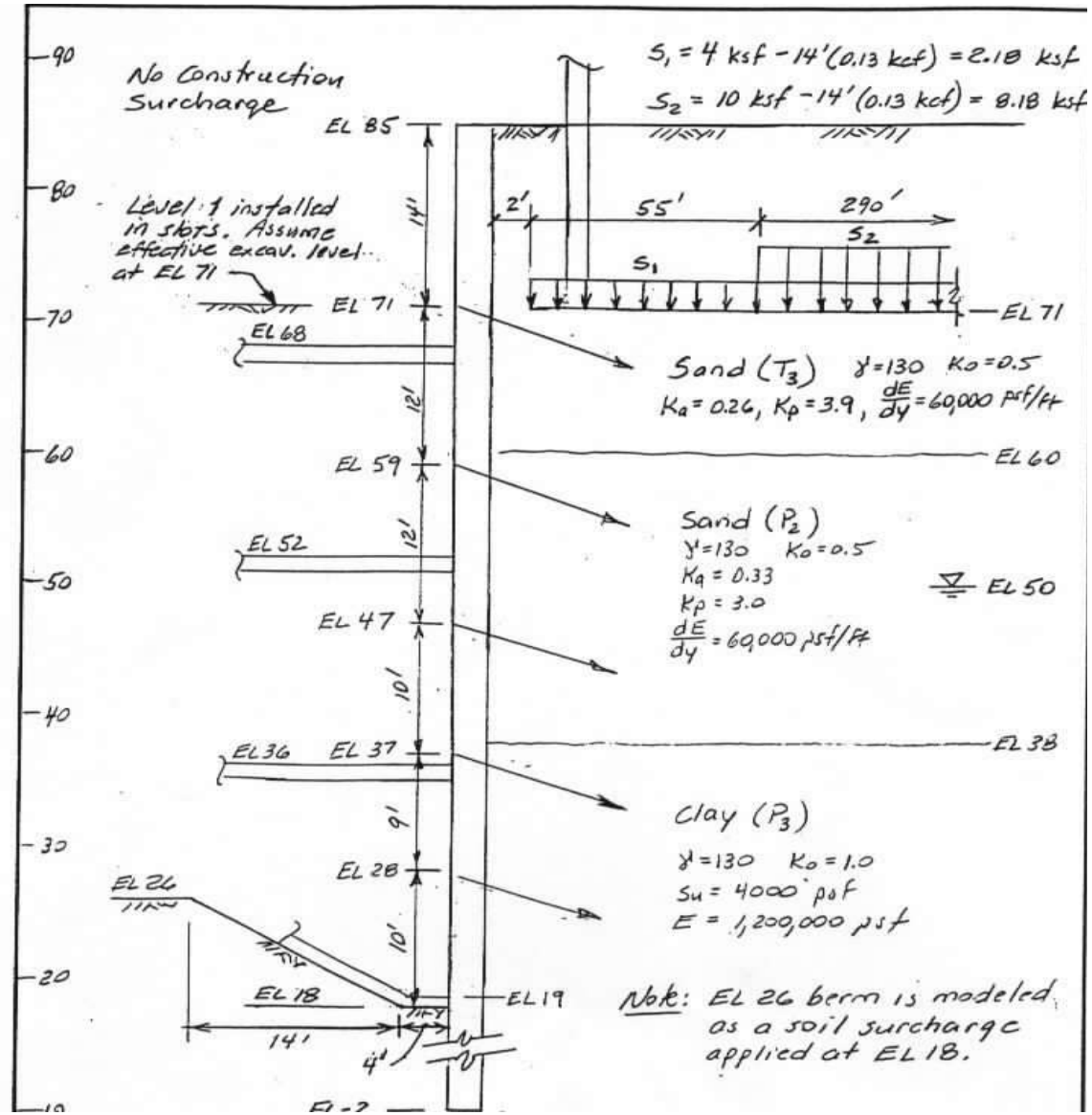
Plan of CVC


SEGMENT 6
SEE SHEET SB1106
SEGMENT 10
SEE SHEET SB1110
SEGMENT 14
SEE SHEET SB1114
SEGMENT 16
SEE SHEET SB1116
SEGMENT 5
SEE SHEET SB1105
SEGMENT 9
SEE SHEET SB1109
SEGMENT 13
SEE SHEET SB1113
JET GROUT CUTOFF WALLS EXTEND FOR 1/2 THE LENGTH OF SERVICE TUNNEL
JET GROUT CUTOFF WALL EXTENDING FROM EL.66' (10' ABOVE DESIGN GW ELEV.) TO 15' BELOW BOTTOM OF EXCAVATION FOR SERVICE LEVEL
JET GROUT CUTOFF WALL EXTENDING FROM EL.66' TO 15' BELOW BOTTOM OF EXCAVATION FOR SERVICE LEVEL
JET GROUT CUTOFF WALL FROM EL.40' TO 15' BELOW BOTTOM OF EXCAVATION FOR SERVICE LEVEL
SOIL MIX WALL REINFORCED WITH H-PILES
JET GROUT OR SOIL MIX CUTOFF WALL FROM EL.40' TO 15' BELOW BOTTOM OF EXCAVATION FOR SERVICE LEVEL

Creative Construction Approach

- Original design based on top-down construction
  - Conventional slurry walls for excavation support
  - Columns installed in drilled holes
  - Top deck installed and used as bracing
  - Excavation under deck with conventional tieback support
    - Limited headroom, small equipment, slow construction
    - No pre-loading of top brace
    - Typical tieback pre-stress to 75% of design load
- Contractor's Creative Approach
  - Provide extra capacity in slurry walls and tiebacks along Capitol
  - Tiebacks pre-stressed up to 120% of design load or until net backward movement
  - Open excavation to subgrade followed by column installation
  - Top deck installation followed by interior construction
  - Experience suggested could meet movement control criteria
  - Resulted in lower cost ($8M savings) and faster construction

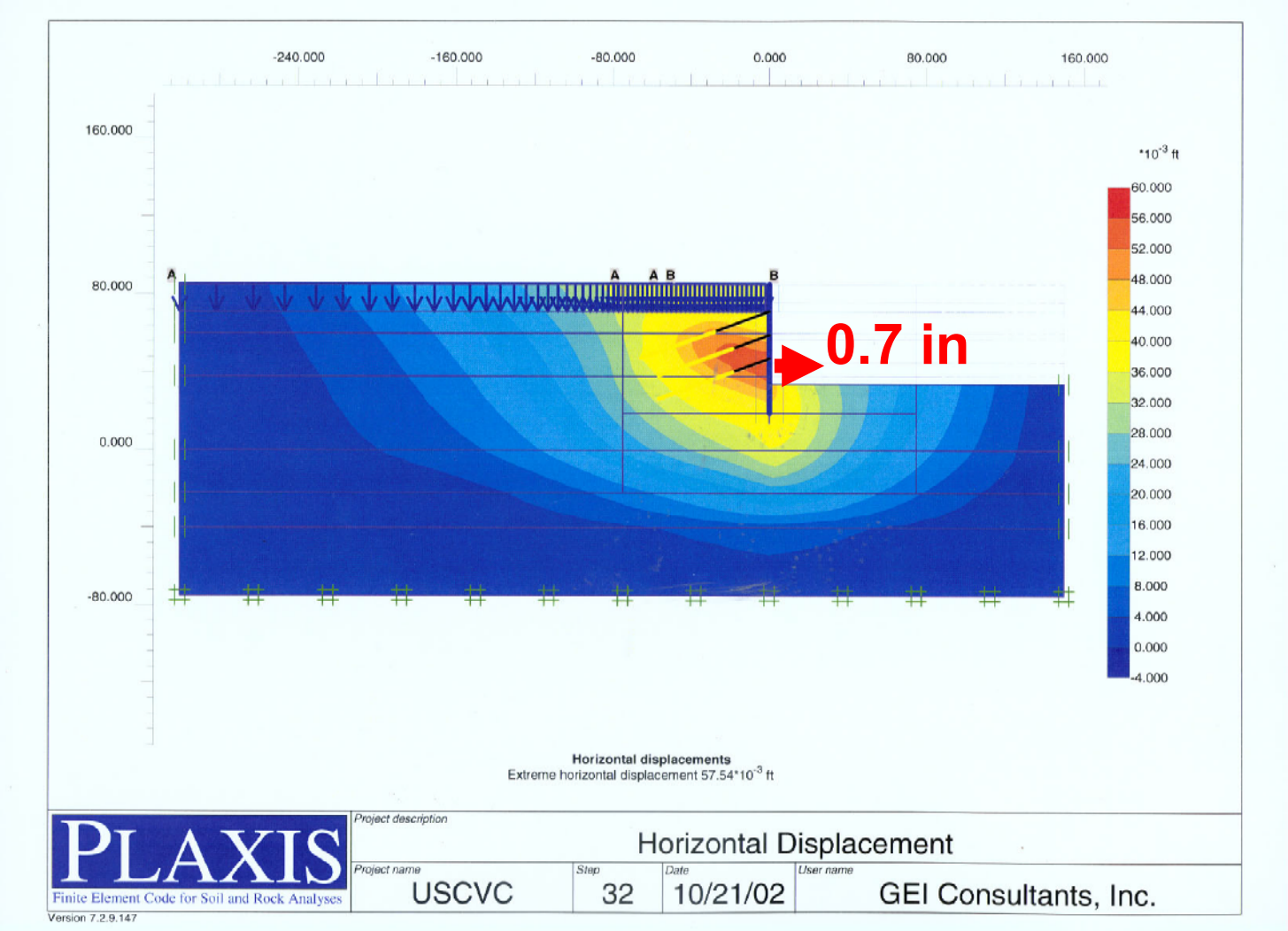
Simplified Design Profile



--- Depth of Typical Excavation

-- Depth at Deep Cuts Along Face of Capitol

Predicted Lateral Wall Movement
Typical 40-Foot Deep Cut



Predicted Vertical Ground Movement
Typical 40-Foot Deep Cut

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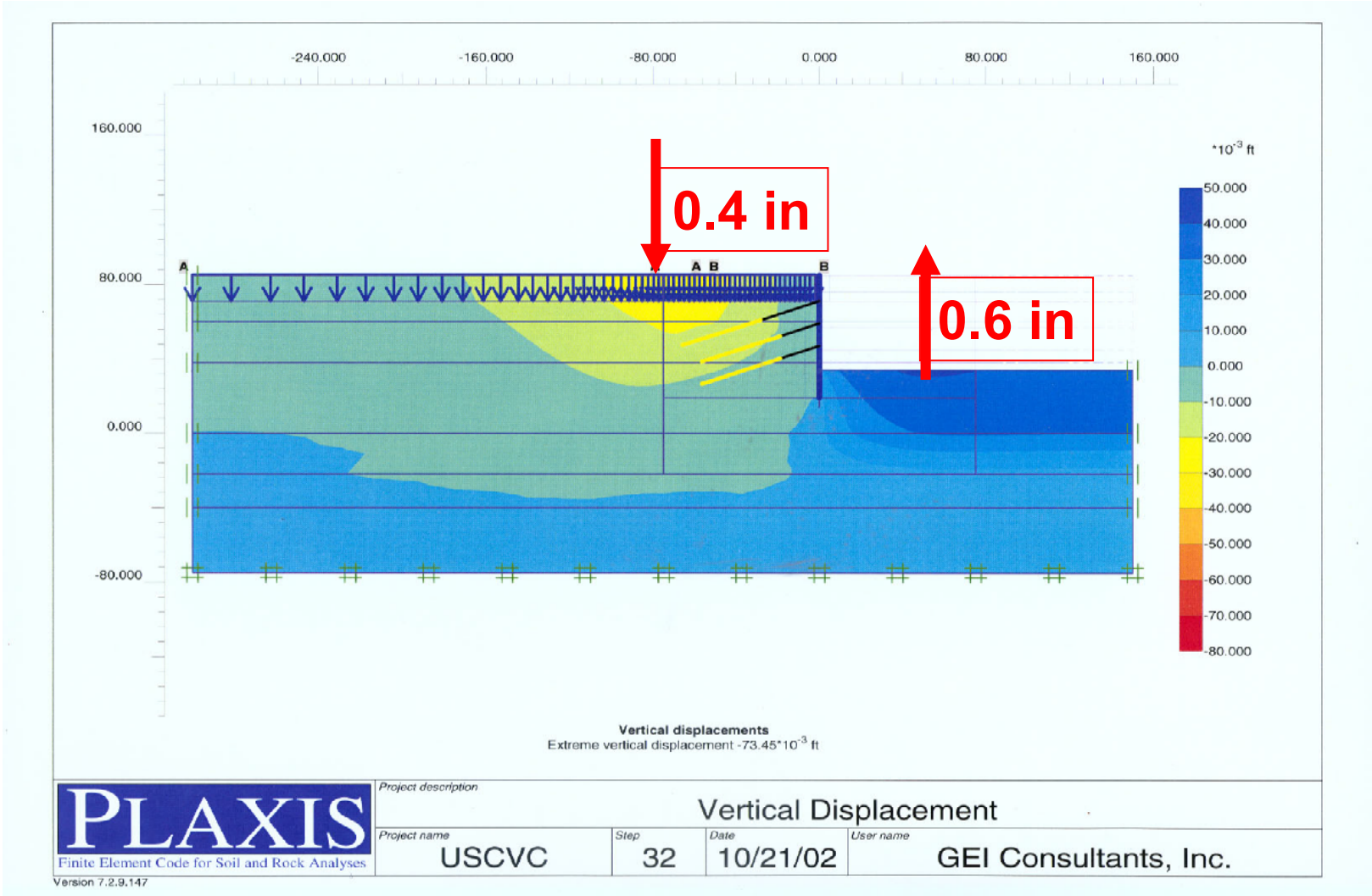
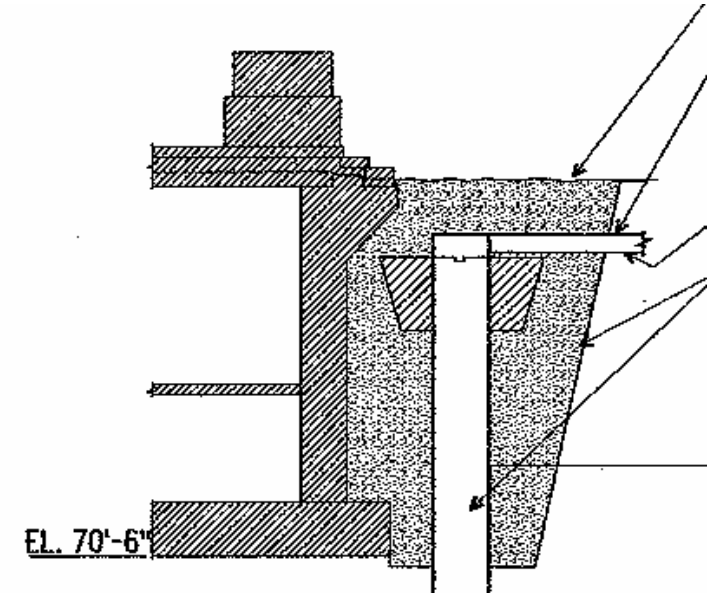


Slurry Guidewalls



Hydraulic Clamshell for Slurry Wall Excavation

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Slurry Wall Cage Installation

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Tieback Installation

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Completed Wall

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Predicted vs. Actual Wall Movements Deep Section along Capitol

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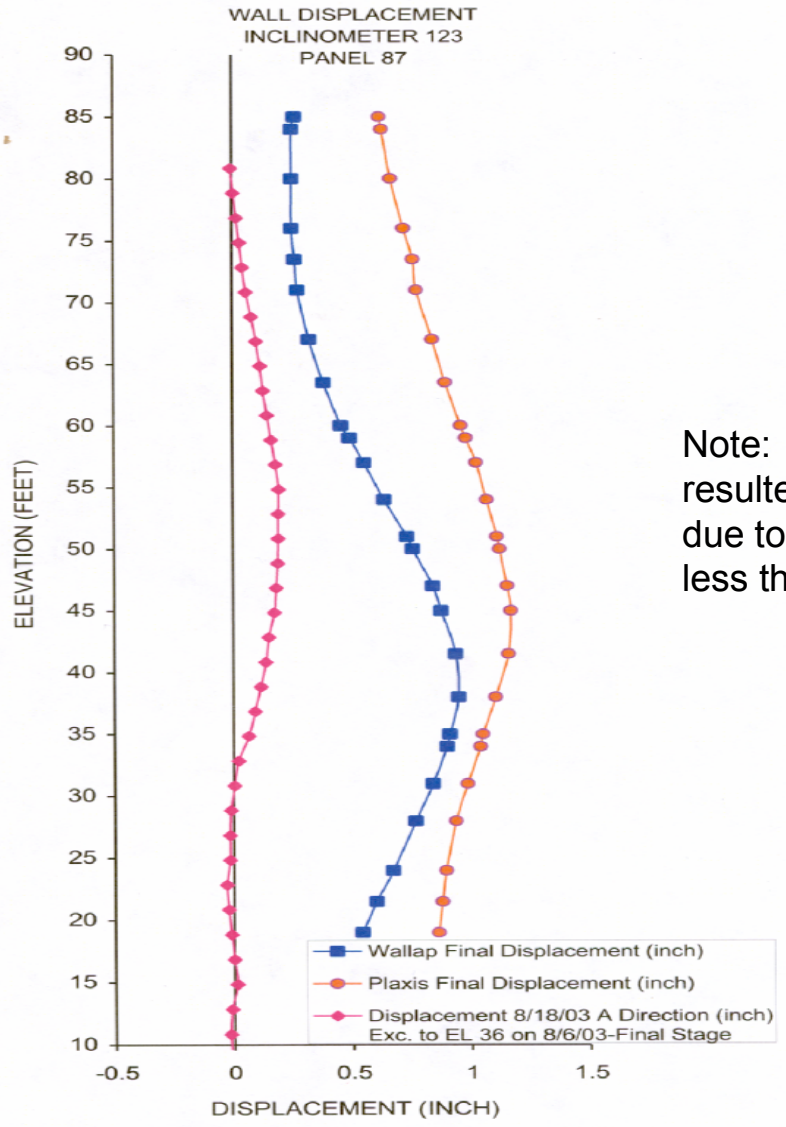

Note: Actual lateral wall movements resulted in angular distortion of Capitol due to differential settlement that was less than allowable value of 1 : 1000.

Predicted vs. Actual Wall Deflection
Typical Cut away from Capitol

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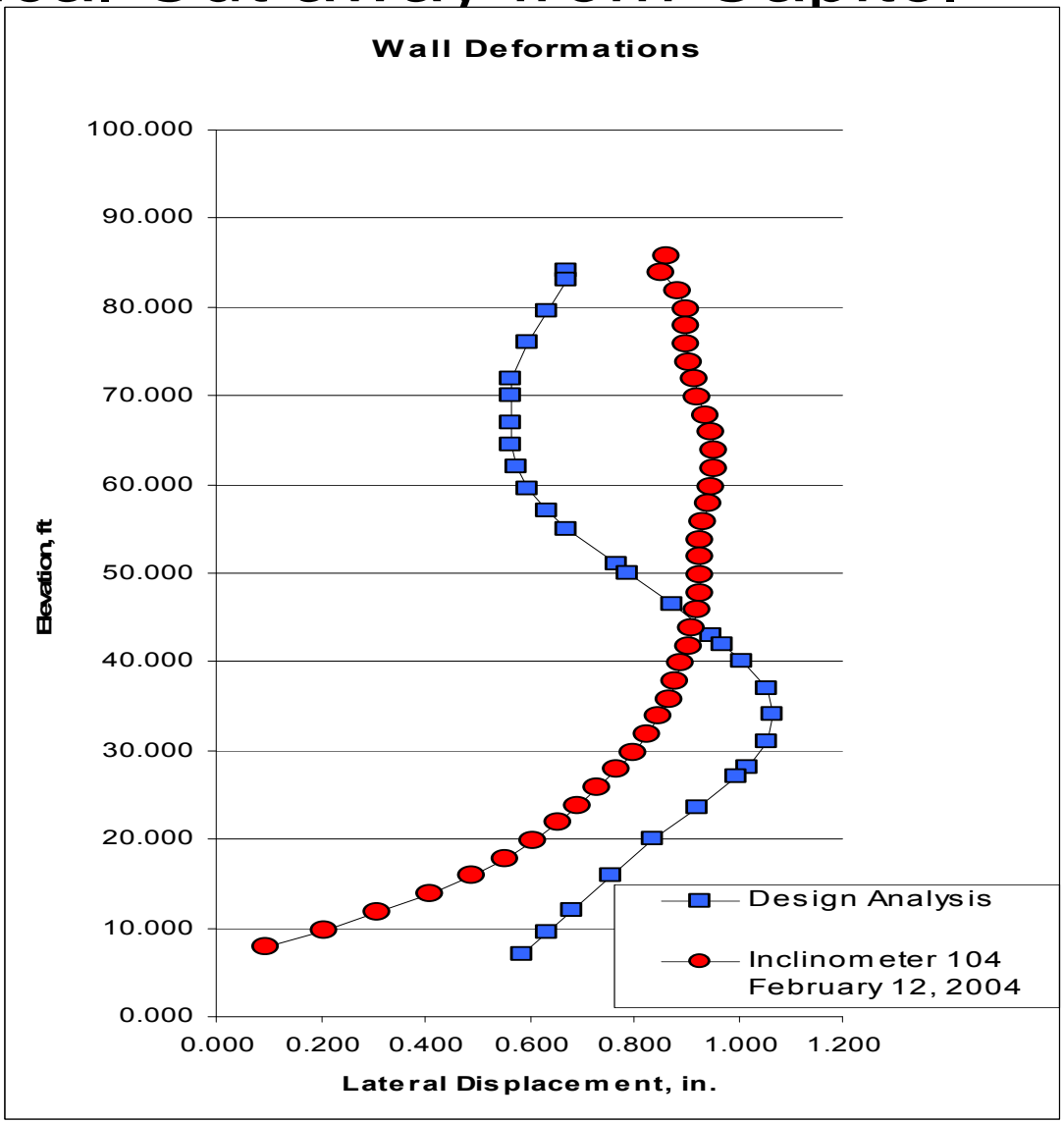

Results: Pro-active engineering with M^3 yields excellent movement control

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CA/T Tunnel Jacking

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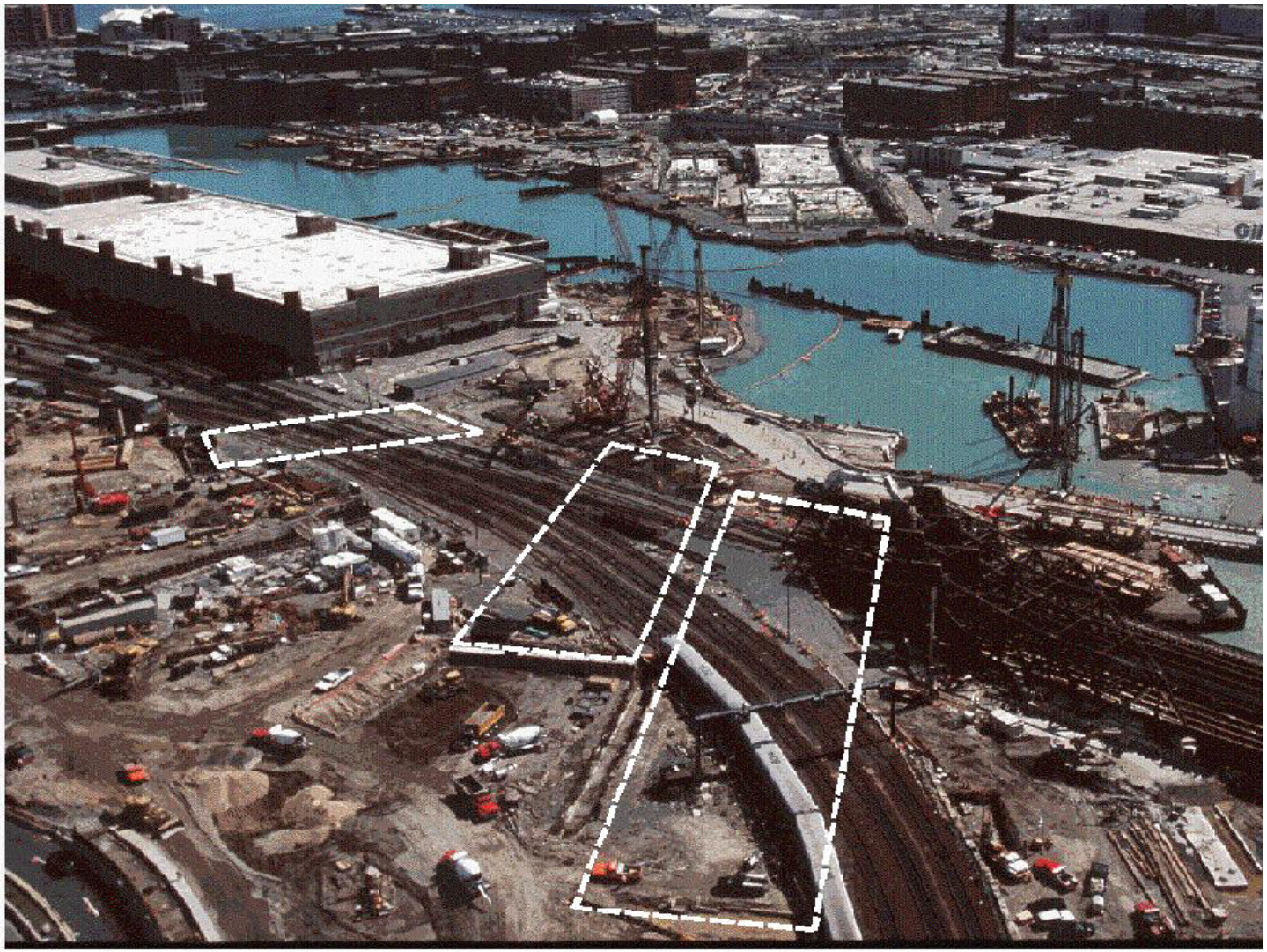

CA/T Tunnel Jacking

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Re-Design of Tunnel Jacking Approach and Procedures

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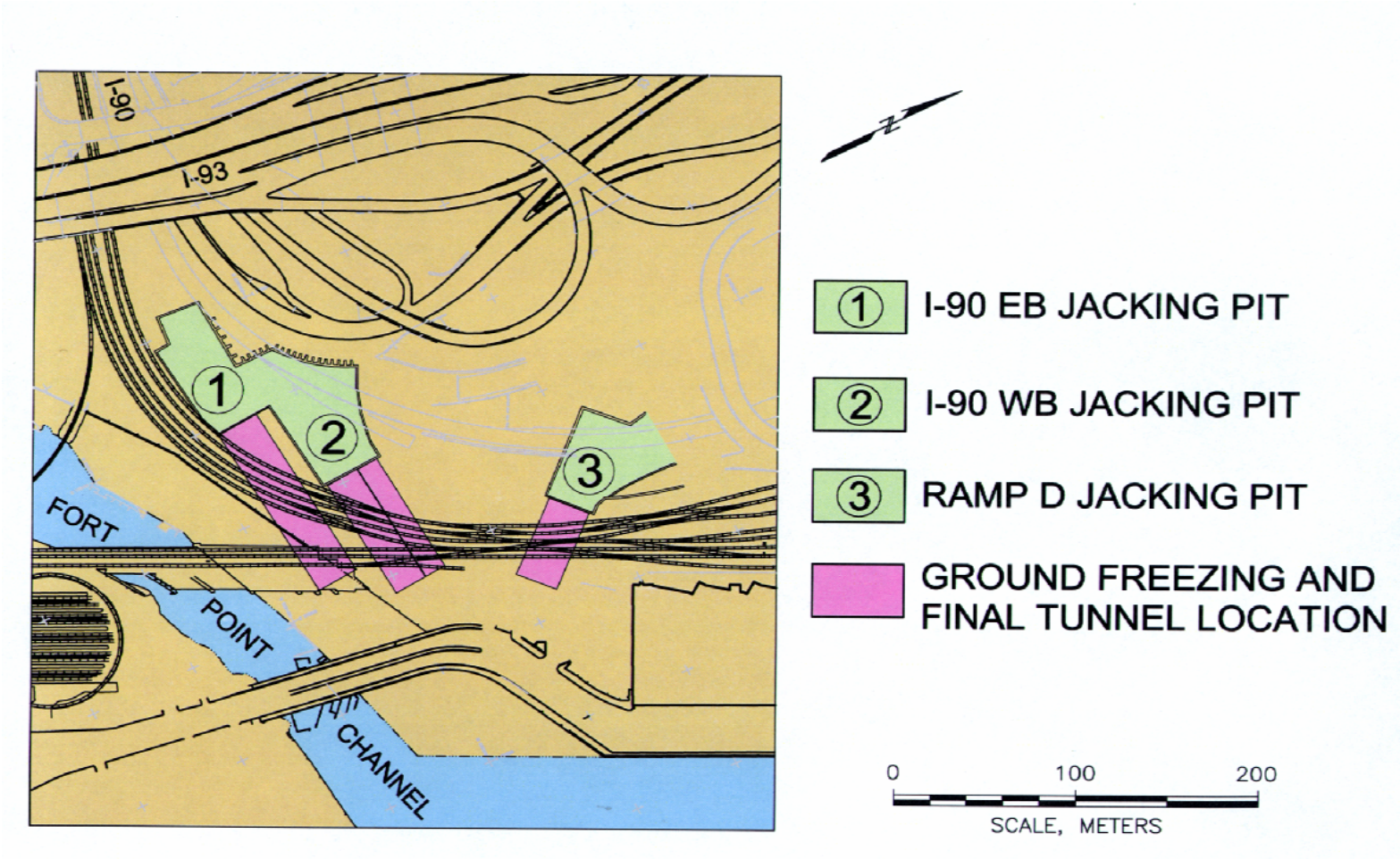
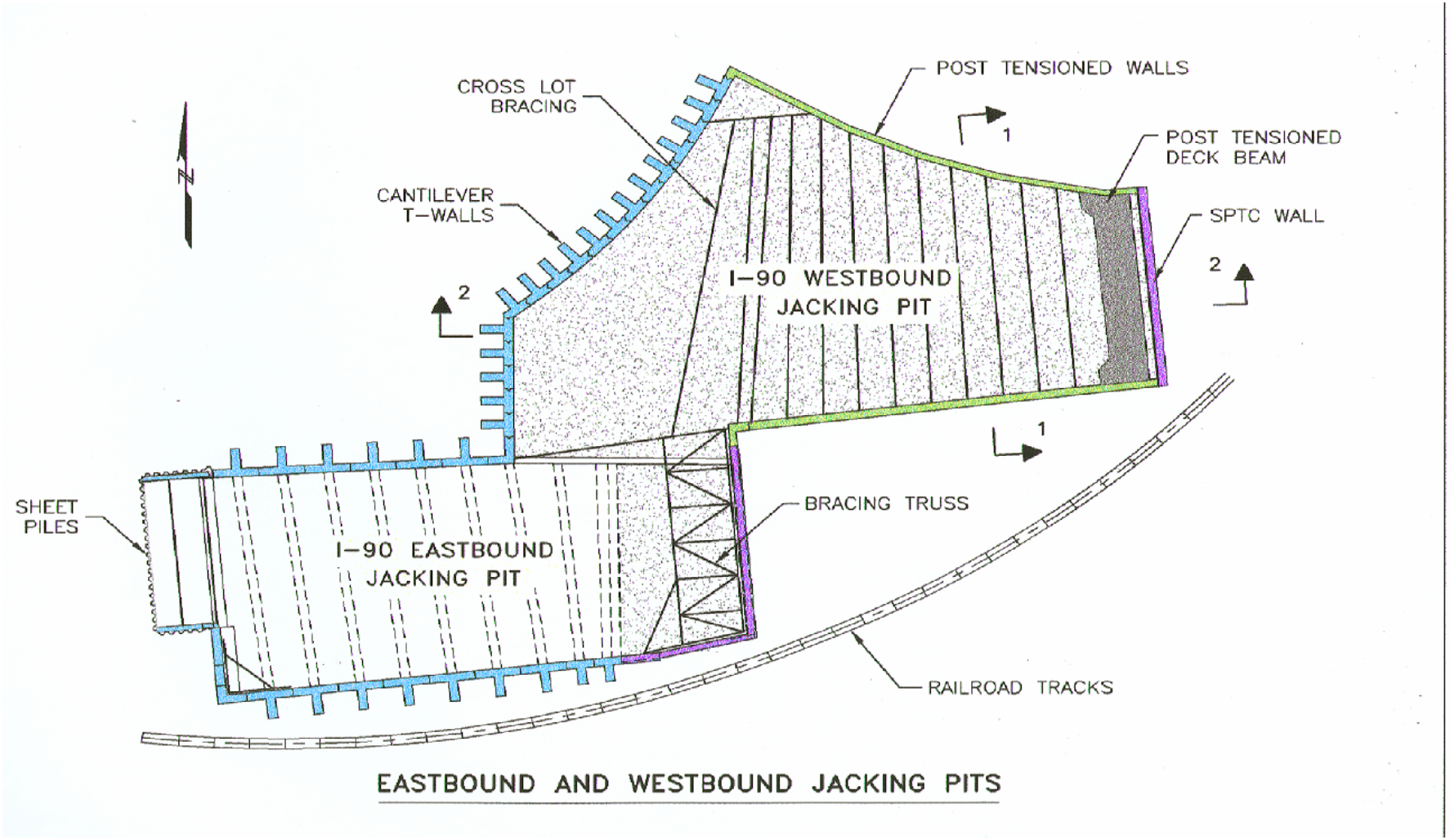
- Original Design
  - Tunnel jacking into existing soil
  - Soil grouting for roof stabilization ahead of face and ground water cutoff
  - Removal of obstructions as encountered
  - Three intermediate jacking stations to limit jacking loads
  - Risks from ground loss, obstructions, re-starting after stopping, tunnel diving in soft subgrade soils

- Value Engineering Approach
  - Ground freezing to stabilize soil in advance of jacking
  - Install walls before freezing, allow controlled yielding of headwalls
  - Removal of frozen soil and obstructions with road-headers
  - Fewer intermediate jacking stations and larger jacking forces
  - Design jacking pits to accommodate ground movements and loads from freezing
  - Reduced risks and better grade control

Jacking Pits



Layout of Jacking Pits



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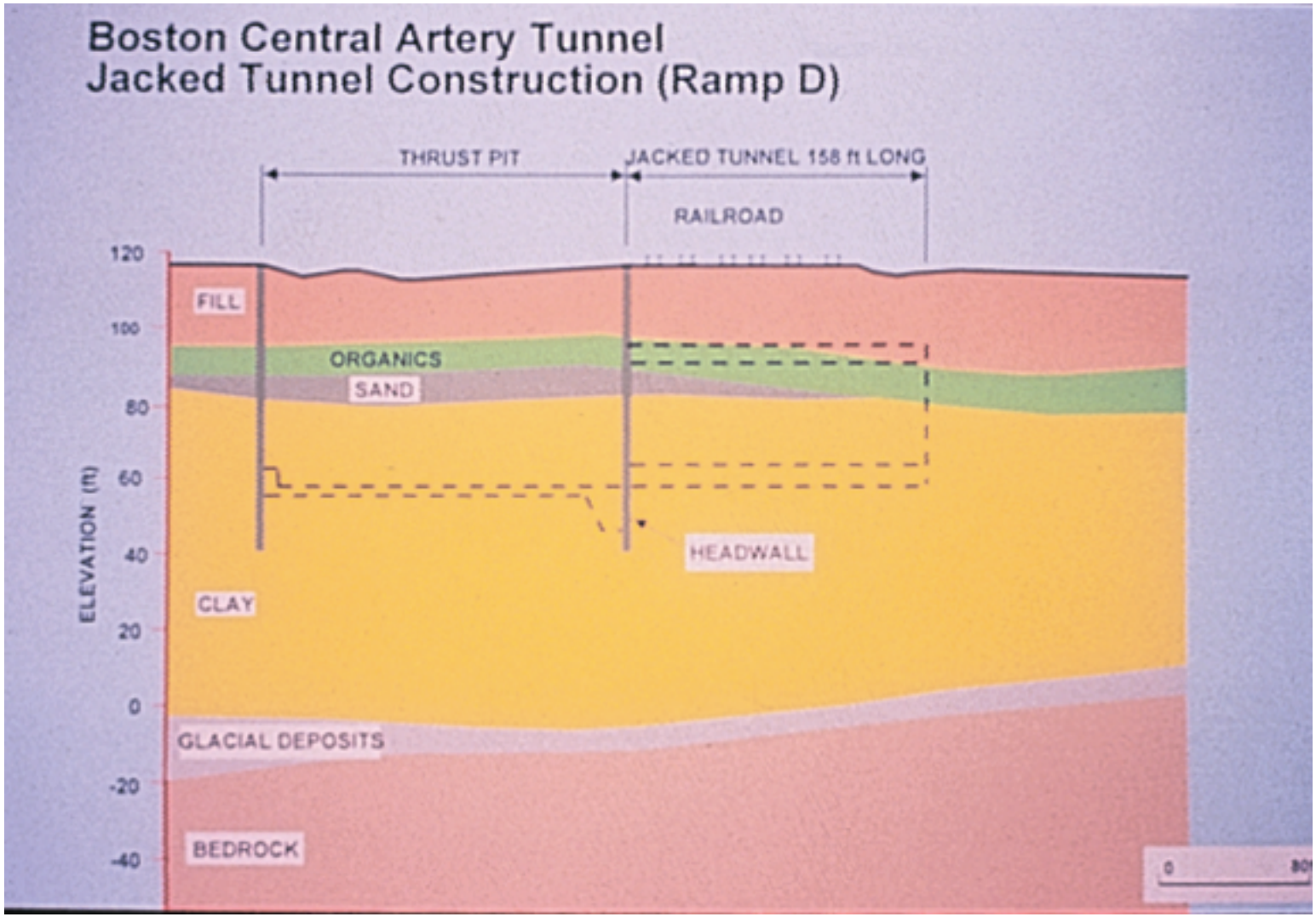

Longitudinal Section of Jacking Pit

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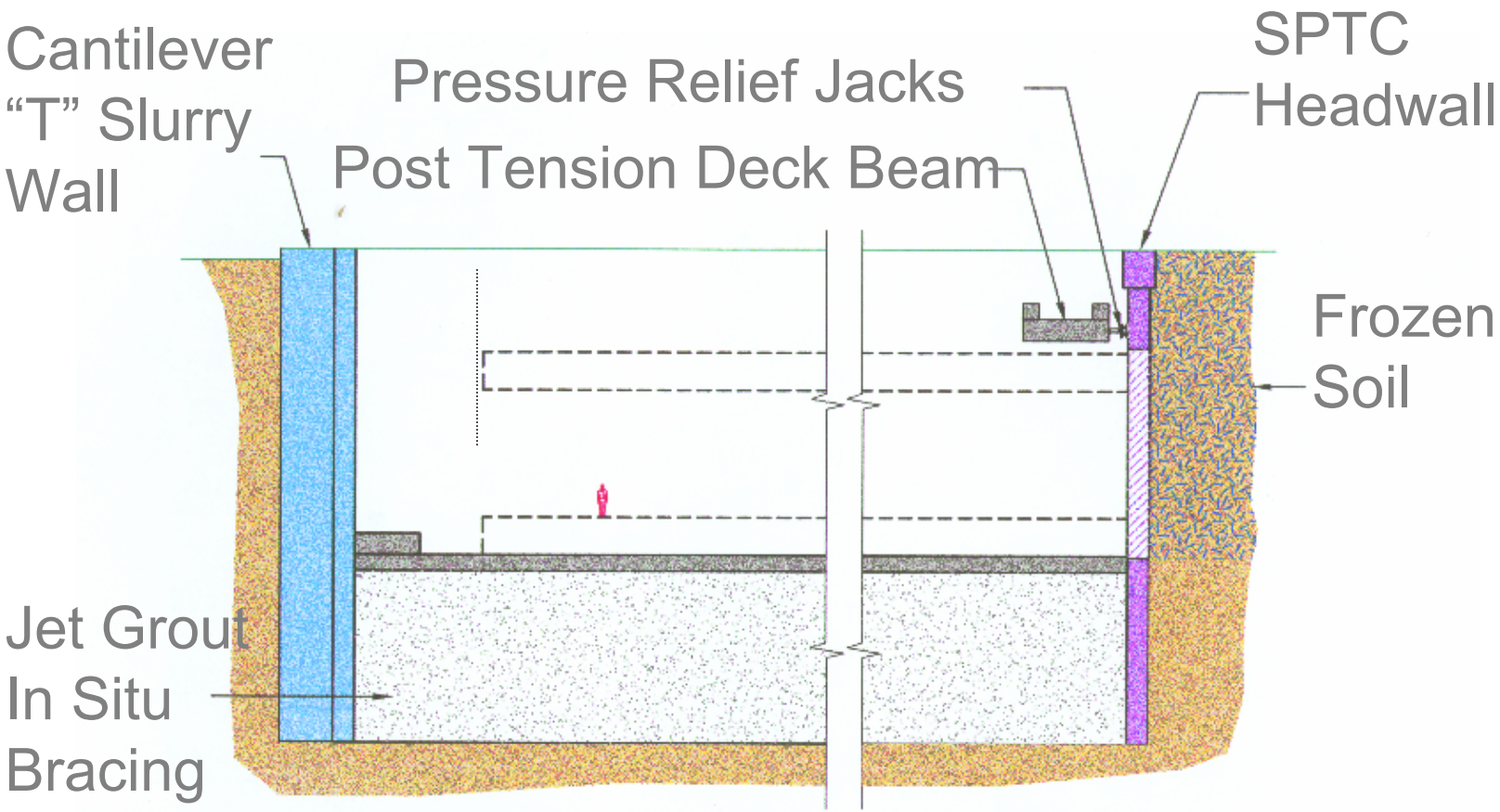

Typical Longitudinal Section of Tunnel Jacking

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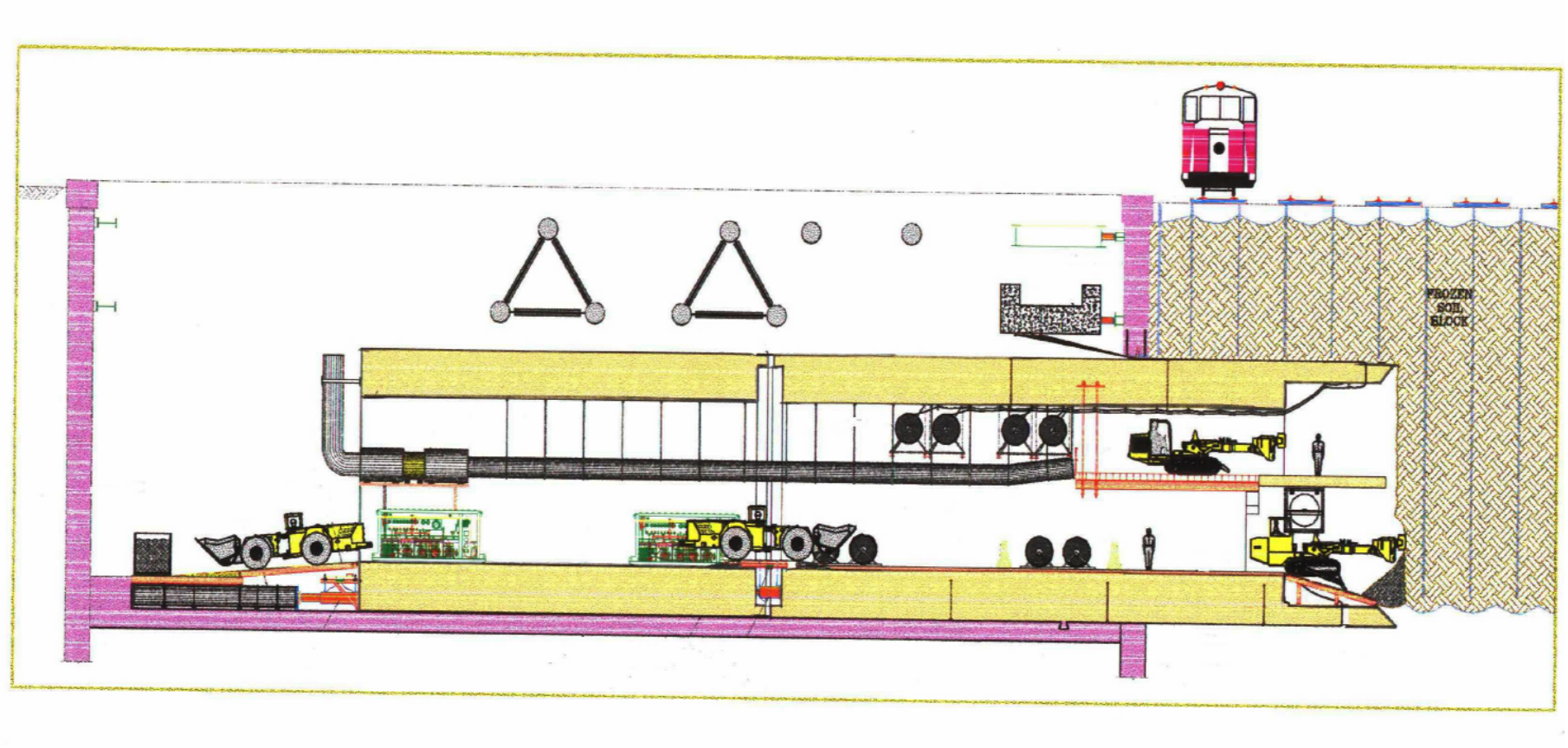
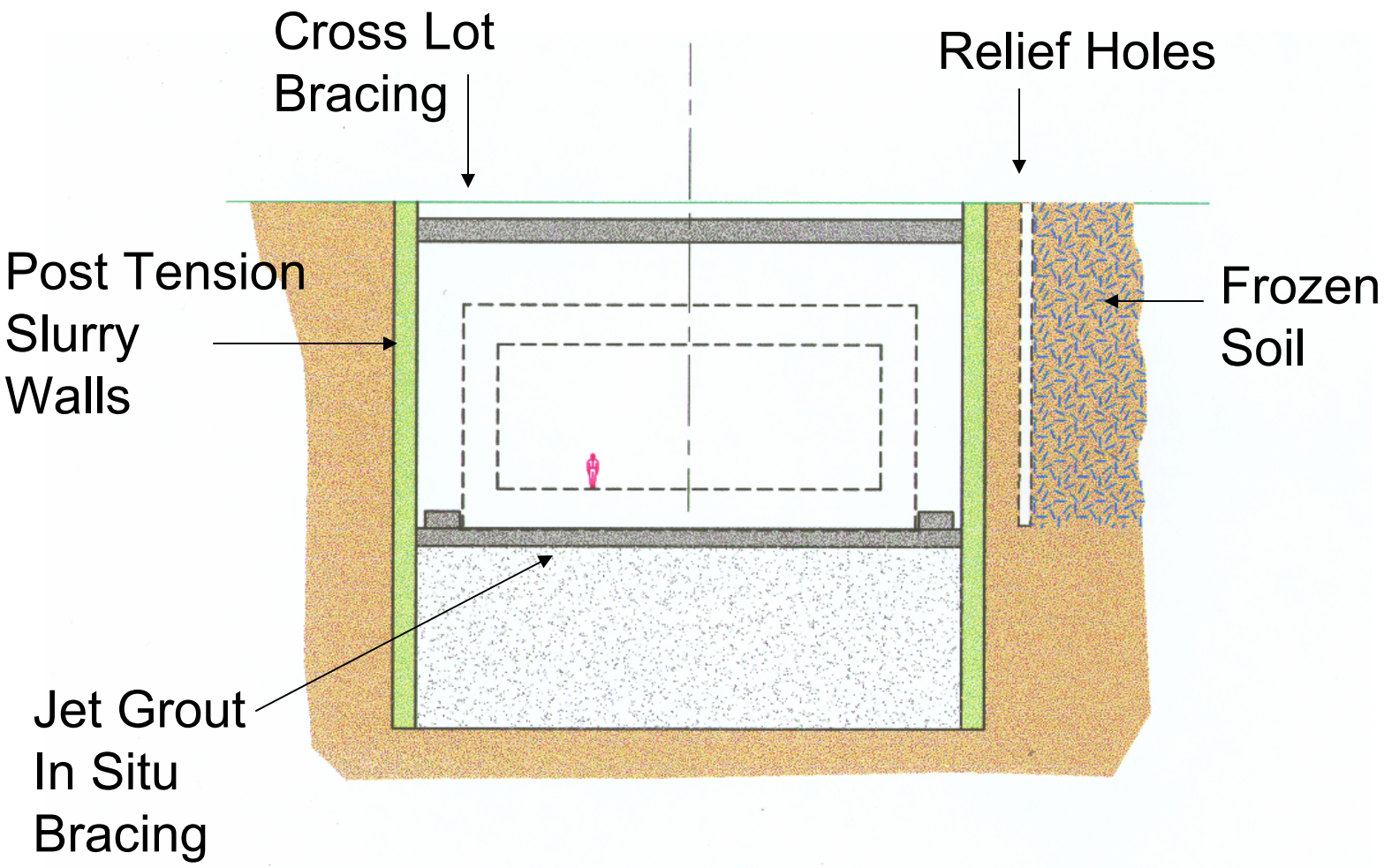
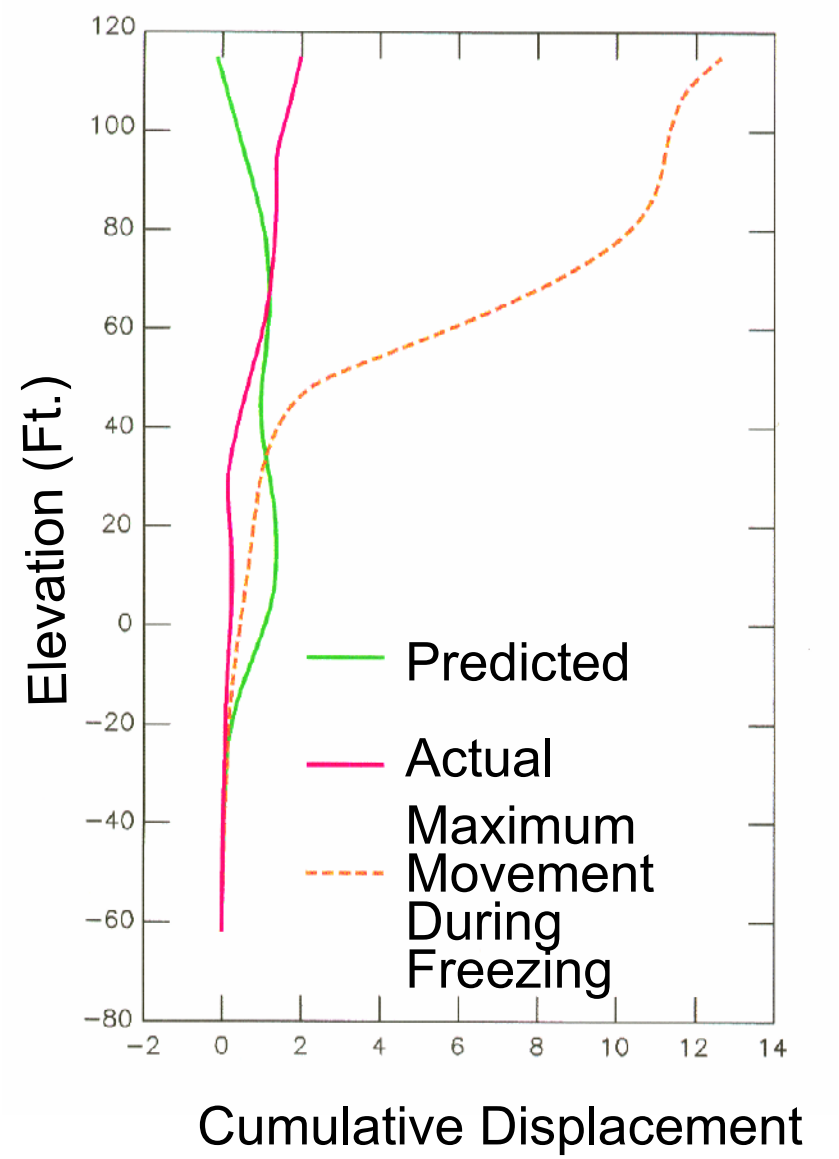


Cross Section of Jacking Pit

GEI Consultants



Plot of Jacking Pit Wall Deflection



- **Within CA/T project limits for downstage excavation**
- **Wall behavior similar to walls with multiple levels of bracing**
- **Movements during freezing unprecedented**

Pit Wall and Reaction Truss Next to Railroad

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Headwall Reaction Jacks and Truss

Freeze Pipes in Rail Track Area

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Road Header for Excavating Frozen Soil and Obstructions

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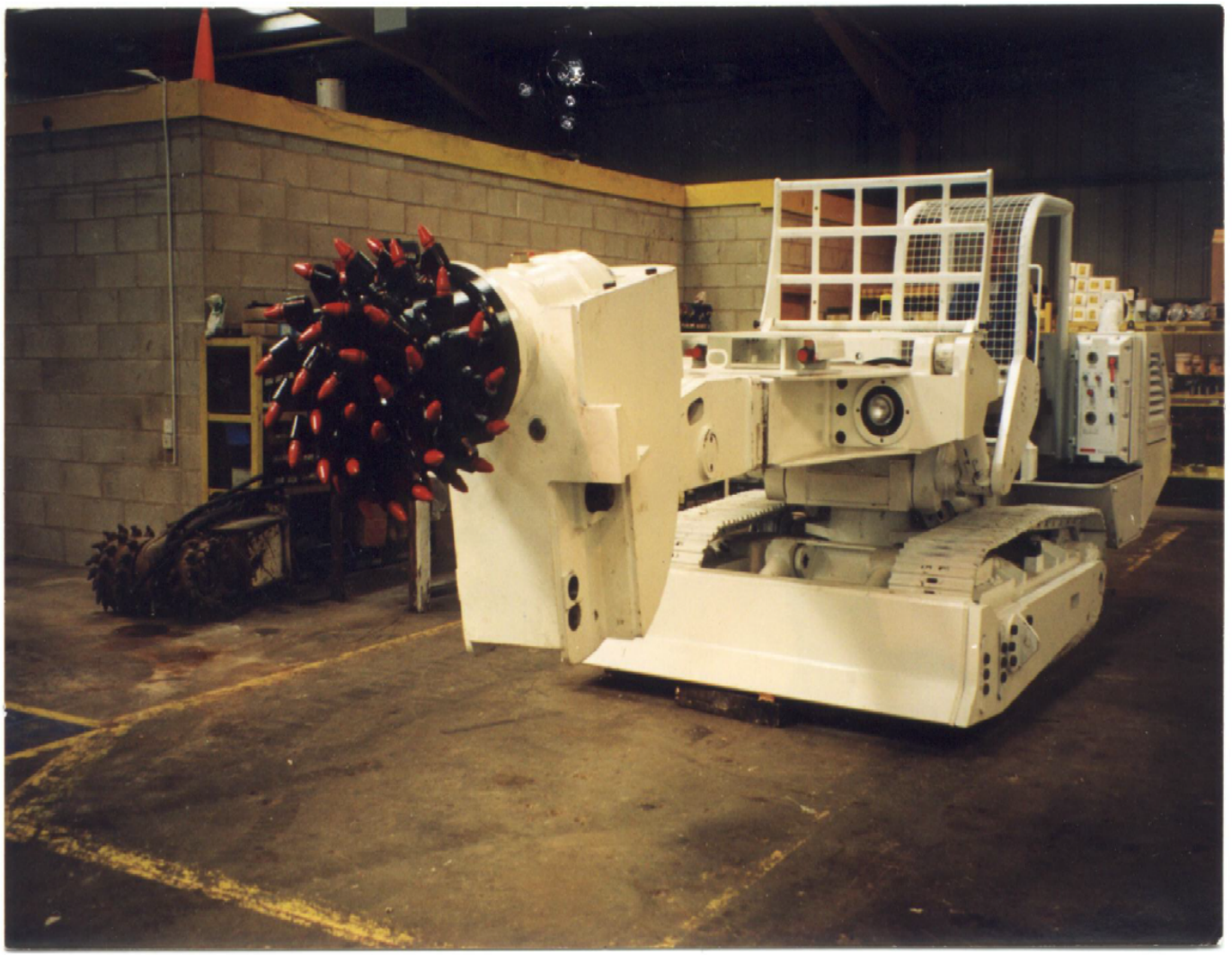

Obstructions During Excavation at Tunnel Face

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Tunnel Jacks in Base of Pit

Results: Creative Engineering with M^3 Allow Safe, Very Large Wall Movements

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